Stormwater infiltration capacity maps: a brief international overview to question French practices

Cartes d'aptitude des sols à l'infiltration des eaux pluviales : un bref panorama pour interroger le cas français

Gerolin A.[1], Dumont E.[2], Degrave M.[1], Pétillon G.[2], Le Nouveau N.[3]

[1] Cerema (Studies and expertise centre on risks, environment, mobility and land use planning), Division for the Eastern Region, 71 rue de la Grande Haie, 54 510 Tomblaine, France. E-mail: aurelie.gerolin@cerema.fr
[2] Cerema, Division for Paris Region, BP 134, rue de l'égalité prolongée - 93 352 Le Bourget, France. E-mail: emmanuel.dumont@cerema.fr
[3] Cerema, Division for territorial development and urban planning, 2 rue Antoine Charial, CS 33927, 69 426 Lyon Cedex 03, France.

RÉSUMÉ

L'infiltration des eaux pluviales est une pratique en développement dans de nombreuses régions. Elle contribue à la prévention des inondations par ruissellement, débordement de réseaux d'assainissement ou de petits cours d'eau, ou bien à la réduction des rejets de temps de pluie dans les milieux récepteurs. Ainsi, en France et à l'international, un nombre croissant de collectivités définit des règles ou des recommandations techniques pour l'infiltration en vue d'une gestion à la source des eaux pluviales. Certaines d'entre elles font le choix de s'appuyer sur des cartes zonant leur territoire selon le potentiel d'aptitude à l'infiltration ou les contraintes environnementales à prendre en compte lors des études préalables. Dans le cadre d'un état des lieux réalisé en France, une analyse de pratiques étrangères a pu être conduite. La présente communication dresse ainsi un bref panorama d'une vingtaine de cartes repérées à l'international (1). Certaines d'entre elles sont par la suite détaillées dans le but d'en décrire les motivations, les méthodologies appliquées pour leur élaboration ainsi que leur utilisation (2). Enfin, une première mise en perspective avec les pratiques françaises est proposée, ayant vocation à être approfondie dans le futur (3).

ABSTRACT

Stormwater infiltration is being applied more and more in many urban areas, mainly as a way to prevent urban floodings or to reduce discharges into receiving waters. A growing number of municipalities and counties are thus defining regulations or guidelines to support infiltration for on-site stormwater management. In order to assess the possibility of infiltrating stormwater within a large territory, some municipalities make use of infiltration capacity maps. These maps aim to define areas according to their infiltration potential or to the environmental constraints. A study that was launched to obtain feedback from French experiences gave the opportunity to gain insight into international practices. This paper presents a short overview of international examples based on twenty three maps (1). It then presents some of these in more detail in order to understand the reasons why they were deemed necessary, to illustrate the methodology applied for their construction and to analyze how they are used (2). Eventually, a first comparison with French experiences is drawn, which will be dealt more in detail in the future (3).

KEYWORDS

Infiltration, mapping, planning, source control, stormwater

INTRODUCTION

Stormwater infiltration is part of Best Management Practices (BMP) for new and existing urban developments, along with evapotranspiration, retention and detention solutions. Whether they are called Sustainable Urban Drainage (SuDS), Low Impact Development (LID), Water Sensitive Urban Design (WSUD), Green Infrastructures (GI) or even *Techniques Alternatives* (TA), best management practices commonly provide solutions for flood mitigation, water quality preservation and provision for recreational areas (Fletcher et *al.*, 2014). Lately, several other benefits have been described by local planners and the scientific community, such as water storage, groundwater recharge, flow regime restoration or biodiversity preservation (*ibid.;* European Commission, 2014). In the field of stormwater management, some of these benefits can only be achieved using infiltration techniques (e.g. for projects promoting no additional stormwater discharges into sewer systems or rivers).

In this context, local authorities are likely to define the potential for infiltration over their whole territory. This has been the case in France where about 30 maps have been identified as a tool for the definition and implementation of a local policy for stormwater management. However, policies for source control measures are far from being the privilege of France as many foreign local authorities have to deal with the impacts of soil sealing. So one can suppose that stormwater infiltration capacity maps are used in different parts of the world and cover a wider range of territorial contexts, objectives and technical considerations. To gain insight into international practices and to question French experiences, a brief international overview was carried out and is presented in this paper.

1 CONTEXT, OBJECTIVES & METHODS

1.1 Very few guidelines for stormwater infiltration capacity maps

Dedicated guidelines for the feasibility of infiltration systems can be found in national documents (ARSIT, 1995; DWA, 2005; Barraud et *al.*, 2009; Cerema and DGALN, 2014) or more generally in stormwater management guidances (VSA, 2002; Woods-Ballard et *al.*, 2007; DWA, 2007; SIA, 2012; MDDEFP, 2014 and others). Local authorities also tend to provide their own guidelines. However, most of these recommendations apply for single and multi-construction projects and do not provide specific guidelines for stormwater infiltration capacity maps. This is the situation in France.

As part of its policy to promote infiltration for source control measures in local stormwater common practices, the French Department of the Environment is thus supporting a study to define guidelines for infiltration capacity maps. To achieve this goal, preliminary work includes the description of several maps available in France - nearly 30 maps to date - and detailed feedbacks for six of them (Vallin et *al.*, 2016). On this occasion, a brief screening has also been conducted on foreign guidelines and existing maps to bring other elements to the discussion.

This paper next summarizes the method used to identify the maps and describes them briefly. Then it presents some in more detail and draws a first comparison between French and foreign practices.

1.2 A stepped methodology to identify foreign maps and guidelines

The identification of stormwater infiltration capacity maps and specific guidelines took place between December 2013 and December 2014. It relied on bibliographical searches on the Internet, among international journals (Science Direct) and through the Novatech and International Conference on Urban Drainage proceedings - only the 2008 and 2011 editions for the latter. The keywords included the term *'map'* along with *'stormwater infiltration'*, *'stormwater infiltrability'*, *'recharge'*, *'rainwater'*, *'BMPs'* or *'SUdS'*, *'soakage'*... Three maps were identified through the proceedings, 2 through Science Direct and ten on the Internet.

At the same time, the members of SOCOMA - SOurce COntrol for stormwater MAnagement - worgroup from the International Water Association were contacted. This provided the opportunity to ask scientists and professionals from other countries about their knowledge on stormwater infiltration capacity maps. Eight maps were brought to our attention during the consultation. These relate to Australia, Belgium, Canada, Germany (2), Japan and the United States (2).

Each map was briefly described. Information deals with general (location, country, map's holder, title of the map, year, map's producer, objective of the map) and technical data (surface area, parameters used to evaluate the potential for infiltration, scale and zoning of the map - including the color and legend of each zone). The information also includes bibliographical references and a go-to person.

Eight maps were then selected according to their geographical boundaries and general objectives to conduct a detailed analysis on a bibliographical basis (reports...) and email discussions. These maps are underlined in Table 1. The analysis focuses on four items: *(i)* the origin/need for the map, *(ii)* the methodology applied for its construction, especially the parameters and criteria to evaluate the potential for infiltration, *(iii)* the description of the map and *(iv)* some feedback on its use. A 3 to 4-page synthesis was made for each case study. When possible, the synthesis was sent to the go-to person for review (Melbourne, Brussels, Great Britain, Toronto Region, Omaha and Geneva Canton to date).

Table 1- Summary of stormwater infiltration capacity maps identified during the investigation (France excluded).

Area	Country	Title of the map(s)	Year	Surface	Origin/objectives
	District areas				
1 catchment in Cincinatti	United-States	Recharge potential	2007	2 km²	Map aiming at delineating areas where rain gardens would contribute the most to groundwater recharge.
	Municipalities, cities				
4 municipa-lities of Mel-bourne area	Australia	Suitability of terrain patterns for bio-filtration approach	2010	251 km^2	Decision tool in order to raise awareness in the community and promote on-site actions for SW management.
Porto Alegre	Brazil	Public Private Spatial Permeability + Retrofit WSUD scenario	2013	497 km^2	Methodology to assess the spatial attributes of the urban landscape to support retrofitting WSUD at different scales.
Hradec Kralove	Czech Republic	Potential of infiltration of BMPs in the existing development	2011	243 km^2	Map created as part of the city development plan in order to integrate best management practices and identify the decoupling potential from the sewer system.
Zittau	Germany	Rainwater management map + Decoupling potential map	2002	66 km^2 ?	Tool created as part of an R&D Project for flood prevention based on decentralized stormwater management techniques in urban and farmed areas. Continued in the NiGIS R&D project.
Coventry	Great Britain	SuDS feasibility map	2012 ?	99 km^2	Decision tool aiming at providing guidance to local planning authorities and developers about options for SuDS on a more detailed basis than the *'Infiltration SuDS map'* available all over Great Britain.
Cologny and Collonge-Bellerive	Switzer-land	Potential infiltration areas and existing works	2008	11 km^2	Map produced for the General water disposal plan (PGEE) of each municipality in order to evaluate infiltration potential on the whole territory, in accordance with the Federal Law on Water protection.
Geneva	Switzer-land	Map of infiltration areas	2006	n.s.	
Omaha	United-States	Soils Investigation for Infiltration-based Green Infrastructure	2014	111 km^2	Map locating the results of site specific soil investigations in urban demolition areas in order to evaluate their potential enhancement for stormwater management (backfills,...).
Eugene	United-States	Infiltration limited areas map	2006	105 km^2	Map aiming at presenting areas which may be infiltration limited due to generalized site conditions.
	Counties, districts, regions, shires				
Sutherland Shire	Australia	Soil infiltration potential	2005	335 km^2 ?	Decision tool from the SW management Development Control Plan of the Council defining specifications for on-site retention to address water supply problems, flood management and preservation of water bodies.
Auckland Region	New-Zealand	Soakage map	2013 ?	n.s.	Maps aiming at providing information to designers at the concept stage regarding the likely availability of soakage in basalt and peat geological context.
Brussels-Capital Region	Belgium	Potential stormwater infiltration areas	2008, 2014	161 km^2	Decision tool part of *"Plan Pluie"*, a regional programme aiming at reducing floodings and runoff in Brussels-Capital Region. Updated in 2014 to take small rainfall events into account.
Toronto Region	Canada	Recharge Area Classification	2006	3 467 km^2	Map defining recommendations for infiltration in urban developments in order to maintain pre-development groundwater recharge rates when possible.
Waimakariri District	New-Zealand	Stormwater disposal – Acceptable means of discharge	n.s	1 200 km^2 ?	n.s.
Dane County	United States	Relative natural or engineered infil. + Relative enhanced infiltration potential	2006	3 206 km^2 ?	Screening tool for the planning and design process to identify infiltration areas for the reduction of overland runoff and recharge of groundwater supplies - possibly by retrofitting in previously developed areas.
	River basins, watersheds				
Emscher drainage basin	Germany	Type of on-site stormwater measures map + Disconnection potential map			Decision tool part of a 15-year stormwater disconnection programme on the watershed to reduce costs for wastewater treatment and restore the river system of ancient mining sites.

Area	Country	Title of the map(s)	Year	Surface	Origin/objectives
Tsurumi River Basin	Japan	Rainwater infiltration potential map	2012 ?	235 km^2	Map part of the Water Master Plan, which was one of the 17 pilot basins selected at a national level to implement a comprehensive flood control programme.
Mystic River watershed	United-States	Suitability map for infiltration BMP	2013	197 km^2 ?	Suitability map to identify best places for implementing stormwater infiltration BMPs (prospective work).
Sonoma Valley Watershed	United States	Groundwater Recharge Potential Map	2011	440 km^2	Decision-making tool to prioritize projects contributing both to groundwater recharge and flood reduction on the watershed.
Laguna Mark West Creek Watershed	United States	Natural Recharge Potential Map + Engineered Recharge Potential Map	2012	655 km^2	Decision-making tool to identify opportunities to alleviate flooding, while possibly recharging groundwater aquifers or providing other benefits.
	Countries				
Great Britain	Great Britain	Infiltration SuDS map	2011	229 850 km^2	Decision tools aiming at providing initial guidance to development planners and local governments for SuDS implementation following the approbation of the 2010 Flood&Water Management Act.

2 RESULTS OF THE INVESTIGATION

2.1 Screening of international maps and guidelines

22 maps were identified: 9 from America, 8 from Europe excluding France, 4 from Oceania and 1 from Asia. A short description is provided in Table1. Recharge maps, maps only assessing groundwater vulnerability and infiltrability maps only used to calibrate distributed hydrological or groundwater models are not taken into account. Anyway, the distinction was not always easy to make and one could rightly discuss it.

One can note that the geographical boundaries of each map deeply depend on the jurisdiction for stormwater management, but also for planning and development. During the investigation, go-to persons might be able to tell whether the use of the kind of maps they were contacted for was quite common or on the rise in its country. This appears to be the case for Germany, Japan and Switzerland.

In Japan, guidelines for *'permeability maps'* are available through the example of the Shingashi River basin (411 km^2) referred to in national guidelines (ARSIT, 1995). The map was built using *in-situ* permeability tests conducted from 1980 to 1993 on 62 sites and 71 times. Considering also the levels of groundwater, it was then used to define three areas: area suitable for installing infiltration facilities, area not suitable for installing them and area needing surveys.

In Switzerland, the mapping of *'potential infiltration areas'* is actually mandatory in accordance with the Federal Law on Water protection. To assist municipalities, the Canton of Geneva wrote regional guidelines for this kind of map inspired from national recommendations (État de Genève, 2005). The parameters used are soil permeability, groundwater depth and thickness of superficial deposits. Threshold values are clearly defined in the guidance. Other constraints are taken into account: ground stability, contaminated soils, gravel pits, springs, wells, etc. to reach three different categories: good potential, potential to be determined on a case by case basis, poor potential or infiltration forbidden.

2.2 Detailed analysis

2.2.1 Infiltration mapping as a tool to implement regulations in Great Britain and Switzerland

Following the 2007 intensive flooding across the United Kingdom, the implementation of the Flood and Water Management Act made the use of SuDS mandatory in new developments, except for individual houses (HMSO, 2010). The publication of National Standards for SuDS was then necessary for the application of the Act. These standards would possibly make infiltration the first solution to be considered by planners and designers. The *Infiltration SuDS Map* project was launched by the British Geological Survey (BGS) in order to provide a decision-making tool for preliminary analysis of ground infiltration potential all over Great Britain (Dearden, 2011).

The construction of this tool benefited from numerous sets of data already available on the whole territory and reclassified by BGS. New data were not necessary. The tool is made of 20 individual GIS layers and 4 summary GIS maps derived from a multi-score analysis: Infiltration constraints, Drainage potential, Ground instability and Groundwater protection. As an example, the Ground instability layer shows four categories: Geohazard unlikely, Potential for geohazard, Significant potential for geohazard, Very significant constraints. The drainage potential summary layer is shown on Figure 1.

These maps are made for strategic planning and preliminary evaluation for construction projects. As they are not freely available, purchase of an Infiltration *SuDS GeoReport*®, subscription for online GIS layers consultation or purchase of GIS layers is necessary. On site investigations still remain necessary on a case by case basis. The success of these maps has been limited up to now (pers. com. BGS). Their use in the future is hard to predict as non-statutory technical Standards for SuDS issued in March 2015 do not give priority to infiltration upon retention or detention (DEFRA, 2015).

By comparison, the Swiss federal Law on Water protection has given priority to the infiltration of non polluted stormwater since 1991. Municipal general drainage plans (PGEE) locate areas where non-polluted water can infiltrate. Guidelines are available from the Swiss Water Association (VSA) and in a dedicated guideline for the Canton of Geneva (cf. § 2.1). The maps are mainly used for information. They prove to be useful for the Canton which validates technical solutions for stormwater management, but not for municipalities. For the case of Geneva Canton, on site investigations remain necessary for construction projects except for areas with poor infiltration potential. In this case, project holders are free not to carry out a feasibility study (pers. com. Canton of Geneva).

2.2.2 Studying the decoupling of stormwater from combined sewers in existing areas: case studies of Hradec Kralove, Brussels-Capital and Omaha

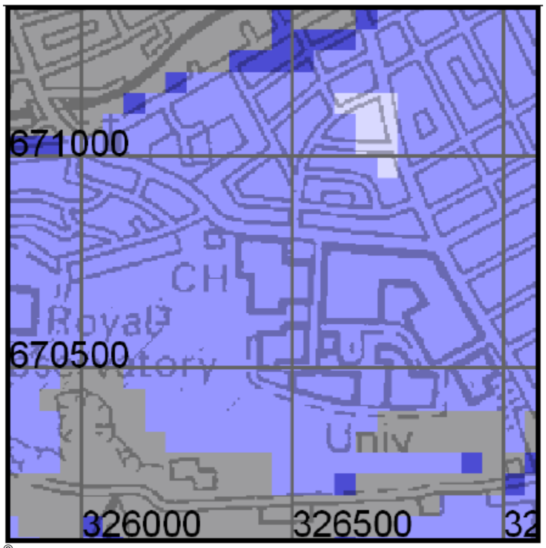
Infiltration is also the first direction for public policy regarding stormwater management in Czech Republic (2009 Water Act - Directive č. 501/2006 Sb). In 2011, an exploratory study was launched on the municipality of Hradec Kralove where source control management is an important component of urban planning. The goals were to evaluate the potential for decoupling stormwater from the combined sewer system in existing buildings and to implement best management practices (Suchanek et *al.*, 2013). Multi-criteria analysis not only took ground potential for infiltration into account but also other constraints for the feasibility of SuDS: nature of building, contaminated sites, slope, owners (public/private). The methodology gave particular attention to space availability and property owners, making infiltration only a component of the mapping (Figure 2). 92 evaluation sheets were elaborated through the territory and showed that 15% of impervious areas could be decoupled from existing buildings. Streets and roads are also investigated.

Reducing combined sewer overflows is also an objective for the administration of Brussels-Capital. In this context, a map was developed to evaluate the potential for infiltration in the region, especially for districts of a certain area. Attention was put on the potential for infiltration of small rainfall events causing Combined Sewer Overflows (CSOs) and pollution of the water resources (return period less than 5 years). In this regard, silty soils which were previously considered as unsuitable for infiltration (Claeys and De Bondt, 2008) were included in the mapping, which represents a noteworthy area (Figure 3). A second map defines the acceptable values of discharges into the sewers depending of the infiltration areas (Bruxelles Environnement, 2014). On site investigations remain necessary for construction projects. Feedback is not available yet.

In the United States, the US Environmental Protection Agency is responsible for the implementation of the National Pollutant Discharge Elimination System program which includes mitigation of CSOs. In 2010, the Agency launched a research project to assess the possibility of using vacant lots in towns to install infiltration areas and decouple stormwater from sewers (US EPA, 2011). First developed in Cincinnati, Ohio, the methodology to assess soil suitability was adapted for other cities. Among these, Omaha, Nebraska, suffers from severe CSOs and is engaged in a large plan to modernize its sewer network. Investigations were carried out on 15 zones with boreholes for surface soil and geological characterization, infiltration tests at the soil surface and in the sub-soil (in boreholes), evaluation of soil wetness, physical-chemical properties (ph, Cation-Exchange Capacity, Carbon and TN, Ca, Cu, Mg, P, K, S and Zn), rock fragment percentage and characterization of backfills (Shuster et *al.*, 2014). The results are located on a map. However, it was decided not to turn to a map covering the entire territory because of strong discrepancies in urban soils characteristics. Instead, sheets are available for each lot. They show the results of soil investigations and give information to size best management practices such as raingardens when the soil features allow for them.

2.2.3 Introducing groundwater recharge and soil functions considerations into planning: case studies of Sonoma Valley, Toronto Region and Melbourne area

Sonoma Creek Watershed, California, suffers from floods and intensive summer droughts. Lower groundwater levels threaten water quality and can cause saltwater intrusion. To preserve groundwater recharge areas in the watershed, the Sonoma County Water Agency (SCWA) and Ecology Center (SEC) launched the *Recharge Potential Mapping Project*. This study is part of the Sonoma Valley groundwater management plan adopted in 2007. Several previous studies and GIS data were already available. After being compiled and reclassified, they were used for a multi-criteria analysis based on four characteristics: vegetation (10%), soil type (25%), geology (50%) and slope (15%). Literature and insights from the scientific community helped to define the weighting values (SEC and SCWA, 2011).



Highly compatible for infiltration SuDS.

The subsurface is likely to be suitable for free-draining infiltration SuDS.

Probably compatible for infiltration SuDS.

The subsurface is probably suitable although the design may be influenced by the ground conditions.

Opportunities for bespoke infiltration SuDS.

The subsurface is potentially suitable although the design will be influenced by the ground conditions.

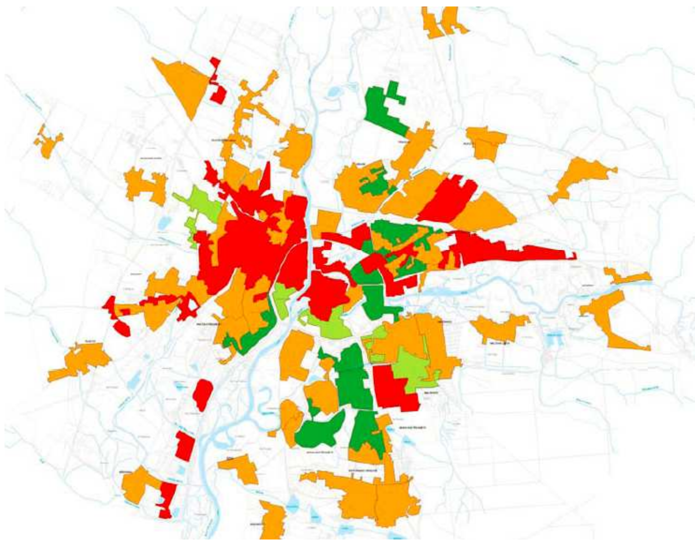
Very significant constraints are indicated.

There is a very significant potential for one or more hazards associated with infiltration.

The Infiltration SuDS map consists of 4 summary maps: infiltration constraints, drainage potential (see opposite), ground instability, groundwater protection.

Use at 1:50 000 scale.

Figure 1 - Infiltration SuDS map - Drainage potential summary map (extract) - Great Britain
The style of the legend was adapted by the authors for the purpose of this paper.
Reproduced with permission of the British Geological Survey © NERC.



Available
Public properties with neighboring public green spaces; no particular constraint for SuDS (swales).

Conditionally available
Mainly private properties; no particular constraint for SuDS. Neighboring public green spaces may leverage the implementation of SuDS.

Not available
Private properties with no particular constraint for SuDS but only surrounded by private spaces.

None
Properties mainly located in the historical center. Technical constraint(s) for SuDS implementation.

Figure 2 - Potential of introduction of BMPs in the existing development - Hradec Kralove (Czech Republic)
Only bold text comes from the original map. The italic text has been added by the authors for the purpose of this paper.

The final map consists of seven recharge potential classified areas (Figure 4). This classification results from a Jenks Natural Breaks Optimization method. It is jointly used with other information on constraints and opportunities of the site: impervious areas, vineyards, protected lands, shallow groundwater, etc. to identify the projects most likely to contribute to groundwater recharge. For a second time, the SCWA launched a study for the construction of a decision-making tool to identify and prioritize projects contributing both to flood reduction and groundwater recharge (ESA PWA et *al.*, 2012). Best management practices such as medium and small-scale stormwater infiltration techniques on rural and urban properties are part of these projects. However, they generally do not appear as priority projects since the methodology is more sensitive to large scale solutions. SCWA thus promotes them in local guidances for stormwater management as they are still of interest, especially in areas with shallow groundwater.

Similarities appear with the experiment conducted by the Toronto and Region Conservation Authority (TRCA) in Canada. In 2012, the Authority issued new guidelines for stormwater management in addition to planning guidelines to achieve both water resources protection and groundwater recharge on a river basin scale. A recharge area classification map was developed based on previous coupled groundwater and surface-water flow models, which provided estimated distributions of water budget parameters. The map consists of four types of recharge areas, ranging from low to significant recharge potential. Recharge rate, groundwater-based drinking system and hydrological connections between groundwater and environmentally significant ecological areas are the main parameters. For all the areas except for the low groundwater recharge area, site specific studies are required to identify pre-development recharge rates, which are used as infiltration targets (TRCA, 2012).

Considerations upon other benefits provided by infiltration also appeared in the maps in Melbourne. In order to raise awareness for stormwater management, to promote biofiltration as well as nature in the city when possible and to provide advice for individual owners, Melbourne Water asked for the construction of *'suitability of terrain patterns for biofiltration approach'* maps for four municipalities (Van de Graaff et *al.*, 2010). They show the suitability of different source control techniques: raised, inground or infiltration raingardens, downpipe disconnections and swales. General parameters used were soil profile, slope and water table level. Then additional parameters were attributed to the soils: saturated hydraulic conductivity, sodicity, salinity, water holding capacity, depth of profile, water holding capacity in profile and internal drainage. The maps used to be publicly available for the *10,000 Raingardens program* which is now completed (pers. com. Melbourne Water).

3 DISCUSSION: WHAT CAN WE LEARN FOR FRENCH PRACTICES?

This paper focuses on the first two items: the origin/need for the maps and the methodology used.

3.1 A variety of maps

Analysis of French maps shows great variety (Vallin et al., 2016). The same conclusion applies to the sample of maps investigated in this paper. Variety comes from the scale of implementation which depends on the jurisdiction of stormwater management (municipalities, counties, etc.) but also on more operational considerations. For instance, the need to account for existing areas led to specific approaches in Hradec Kralove and Omaha. On the other hand, more integrated studies for water resources management need to consider river basins areas such as the Sonoma Valley (see also Table 1) whereas French case studies usually match administrative areas. Great Britain and Switzerland also provide examples for which infiltration capacity maps provide a tool to implement national regulations (see also national pilot river basins in Japan and comprehensive flood control programs). On the other hand, some maps directly result from the need to tackle local environmental constraints on stormwater management (Sonoma County, Toronto Region, see also the Emscher Basin and Auckland Region).

Contrary to what has been observed in France up to date, infiltration is promoted for a wider range of objectives, such as groundwater recharge (Sonoma County, Toronto Region, see also Table 1 for Dane County and Laguna Mark West Creek Watershed). This is visible through the titles given to the maps; similarities can be drawn with the City of Lyon in France. It is also possible to include infiltration capacity maps in a multi-benefit approach (e.g. recharge and flood prevention over a river basin). However, the Sonoma Valley case study shows that some benefits are only noteworthy for a scale of implementation different from urban planning.

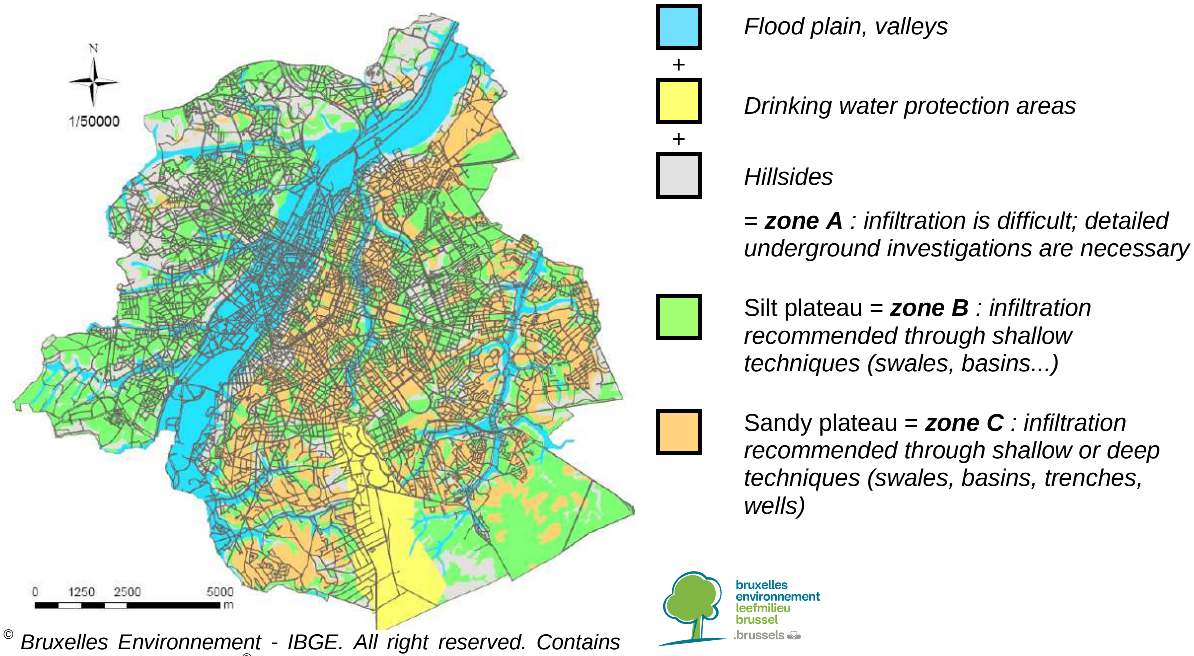


Figure 3 - Potential stormwater infiltration areas - Brussels-Capital Region (Belgium)
The text of the legend was translated and its style was adapted by the authors for the purpose of this paper.

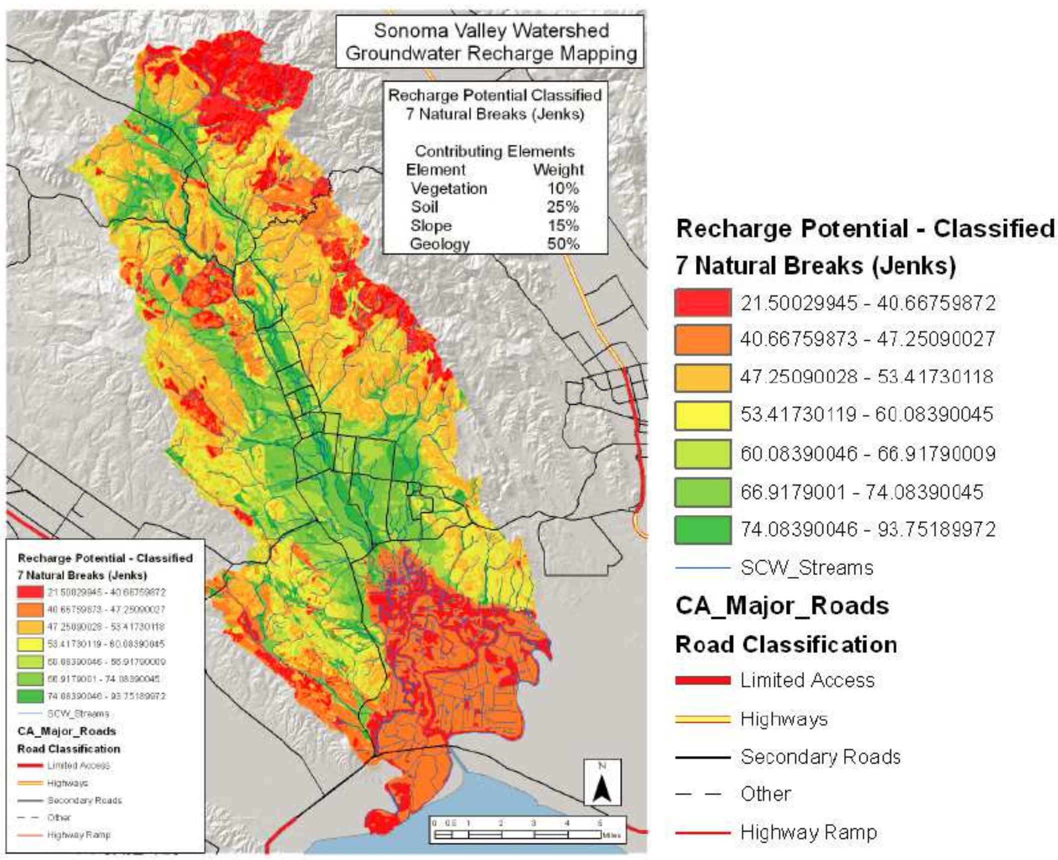


Figure 4 - Sonoma Valley Watershed Groundwater Recharge Mapping - California (United States)

Practitioners from France should note that some maps stand with quantified objectives for stormwater management: 15% of existing impervious areas potentially decoupled on Hradec Kralove. Such an objective is also defined for the Emscher drainage basin (Bandermann et *al.*, 2008).

3.2 Insights for the methodology used

Common parameters are present in almost every map for soil and groundwater considerations (type of soil, depth of groundwater, estimated or in situ permeability). However, differences appear on the use of soil type classifications which are not common in France. Other parameters are common but not systematic (e.g. slope). For the parameters mentioned above however, threshold values (criteria) to assess the suitability for infiltration may be quite different, which is not detailed in this paper, especially for soil permeability according to the objectives of the map. Account for vegetation is only observed on the Sonoma Valley watershed, probably because of large rural areas. The case studies of Omaha and Melbourne also show considerations for pollutant interception through the soil (parameters such as Cation-Exchange Capacity, salinity and pH).

One limit of the screening is to define boundaries between maps evaluating the soil potential for infiltration and maps assessing the feasibility of infiltration techniques. Whereas the first ones may only focus on ground considerations (Great Britain, Brussels-Capital), the second ones have to consider other parameters such as available space, contaminated soils, etc. (Omaha, Melbourne, Hradec Kralove). More, some maps indicate the infiltration techniques which are most suitable for the site. A distinction may occur between shallow and deep techniques (Brussels-Capital, Melbourne, see also Dane County and Laguna Mark West Creek Watershed in Table 1), which is also present in a few maps in France.

Foreign examples barely rely on distributed hydrological or groundwater models. In France, their use for the Cities of Lyon and Strasbourg was motivated by the vulnerability of the aquifer. The insight from other countries suggests that groundwater recharge is another reason (Toronto Region). However, the limit between what we initially called *Stormwater infiltration capacity maps* in this paper and infiltrability data to calibrate hydrological watershed models for diagnosis or predictive planning sometimes became here quite tiny.

The literature shows the complexity of evaluating potential for infiltration in a dense urban context because of special features of urban soils such as backfilling, soil compaction and rock fragment occurrences. One wonders whether mapping really makes sense in these areas. For the case of Omaha, researchers chose only to locate isolated results on a map. This illustrates the limit between strategic planning and operational needs. On the other hand, the need for specific soil investigations on a project by project basis is common for the sample of maps investigated abroad, except for Melbourne area - individual houses. The same conclusion applies for France. The Canton of Geneva chose a transitional option: soil investigations are not required for areas of poor potential.

The recent experience of Brussels-Capital is interesting to how criteria for infiltration can be smoothed when infiltration for small rainfall events is also considered. This trend is on the rise in France but rather at a project scale to date. However, towns or cities such as Paris and surrounding municipalities are turning to a better consideration of small rainfall events.

CONCLUSIONS

The investigation described in this paper showed that stormwater infiltration capacity maps are used in several countries. Without trying to be exhaustive, about 20 maps were documented and briefly presented. One should note that none of them has the same name. The terminology we chose in this paper - stormwater infiltration capacity maps - was not even found in our screening. Differences in terminology surrounding infiltration between countries is probably one reason. The objective given to the maps is surely another one: potential for infiltration, disconnection, recharge, feasibility for SuDS... In any case however, common parameters relate to soils and groundwater characterization. Others are more objective-specific, especially when the feasibility of SuDS is studied and not only the suitability of soils for infiltration. Feedback on their use is not always available but one should make a distinction between maps providing preliminary evaluation for strategic planning and maps showing advice or recommendation for the location and design of infiltration techniques. In most of the cases, specific soil investigations on a project by project basis remain necessary. This first comparison drawn between French and international examples only focused on the origin of the maps and the methodology used for their construction. The work will be continued in the future on other items in order to enhance French guidelines.

REFERENCES

ARSIT (Association for Rainwater Storage and. Infiltration Technology) (1995). *Engineering Guideline for Rainwater Infiltration Facilities Survey and Planning,* ARSIT, Infrastructure Development Institute, 170 p.

Bandermann, S., Sieker, H., Jin,Z., Jakobs, F., Spengler, B. (2008). *Development of an on-site stormwater management information system for the Emscher drainage basin,* 10th International Conference on Urban Drainage, Copenhagen, Denmark, 21-26 August 2005, 8 p.

Barraud et al. (2009) *L'infiltration en questions - Recommandations pour la faisabilité, la conception et la gestion des ouvrages d'infiltration des eaux pluviales en milieu urbain*, Programme ANR Ecopluies, 63 p.

Bruxelles Environnement (2014). *L'infiltration d'eau pluviale – Zonage et recommandations pour l'infiltration d'eau pluviale sur la base des caractéristiques naturelles du sous-sol en Région de Bruxelles Capitale*, recommandation pratique GEQ06, 21st march 2014, 5 p. + appendices.

Cerema, DGALN (2014*). Études de sols pour les ouvrages d'infiltration ou de rétention d'eaux pluviales*, fact sheet n°6, decembre 2014, 16 p.

Claeys P., De Bondt K. (2008). *Cartographie du potentiel d'infiltration-percolation en Région bruxelloise - Rapport de l'étude sur les capacités naturelles d'absorption de l'eau de pluie par les sols en Région de Bruxelles Capitale*, Vrije Universiteit Brussel (VUB), decembre 2008, 27 p. + appendices (unpublished).

Dearden, R. (2011). *User guide for the Infiltration SuDS Map : detailed*. British Geological Survey, 41 p.

DEFRA (Department for Environment, Food and Rural Affairs) (2015). *Sustainable Drainage Systems - Non-statutory technical standards for sustainable drainage systems,* march 2015, London, 4 p.

DWA (German association for water, wastewater and waste) (2005). *Planung, Bau und Betrieb von Anlagen zur Versickerung von Niederschlagswasser*, DWA-A 138, april 2005, ISBN:978-3-937758-66-4.

DWA (German association for water, wastewater and waste) (2007). *Handlungsempfehlungen zum Umgang mit Regenwasser*, Notice DWA-M 153F, august 2007, ISBN:978-3-941089-93-8.

ESA PWA, Daniel B. Stephens & Associates, Parker Groundwater (2012). *Stormwater Management and Groundwater Recharge Scoping Study – Screening Evaluation and Prioritization Memorandum*. SCWA report DW02050.00,46 p.

État de Genève, Domaine de l'Eau (2005). *Plan général d'évacuation des eaux (PGEE) – Notice méthodologique relative à l'élaboration du rapport sur l'état de l'infiltration*, june 2015, version 1.0, 16 p. + appendices.

European Commission (2014). *A guide to support the selection, design and implementation of Natural Water Retention Measures in Europe*, Office of publication, 2014, 98 p., ISBN 978-92-79-46060-9.

Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A. et *al.* (2014). *SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage,* Urban Water Journal, DOI: 10.1080/1573062X.2014.916314.

Her Majesty's Stationery Office (HMSO) (2010). *Floods and Water Management Act*, Chapter 29, HM Government, Her Majesty's Stationery Office.

MDDEFP (Quebec Minister of Sustainable Development) (2014). *Guide de gestion des eaux pluviales,* annexe B.

SEC (Sonoma Ecology Center) and SCWA (Sonoma County Water Agency) (2011). *Sonoma Valley Groundwater Recharge Potential Mapping Project.* SEC Report No. 20100922, 14 p. + appendices.

Shuster, W.D., Dadio, S., Lewis, N. (2014). *Soils Investigation for Infiltration-based Green Infrastructure for Sewershed Management (Omaha, NE).* US Environmental Protection Agency. Report EPA/600/R-14/063.

SIA (Swiss Society of Engineers and Architects) (2012). *Installations pour évacuation des eaux des biens-fonds – Conception et exécution* – Norme Suisse SN 592000:2012

Strayton, G., Lillis, M. (2013). *Stormwater disposal via soakage in the Auckland region.* Auckland Council technical report, TR2013/040, 54 p. + appendices.

Suchanek, M., Vitek, J., Finfrlova, P., Stransky, D., Kabelkova, I. (2013). *Drainage Area Study of the city of Hradec Kralove and its utilization for urban planning,* Novatech 2013, 23-27th june 2013, Lyon, France, 9 p.

TRCA (Toronto and Region Conservation Authority) (2012). *Stormwater Management Criteria*, august 2012, version 1.0, Toronto, ON, 126 p.

US Environmental Protection Agency (2011). *Evaluation of Urban Soils: Suitability for Green Infrastructure or Urban Agriculture.* EPA Publication No. 905R1103, decembre 2011.

Vallin, V., Dumont, E., Pétillon, G., Gerolin, A., Degrave, M., Ferrier, V., Le Nouveau, N. (2016). *Cartographier l'aptitude des sols à l'infiltration des eaux pluviales : l'expérience de 6 collectivités en France*, Novatech 2016, 28th june – 1st july 2016, Lyon, France, 10 p. (accepted).

Van de Graaff & Associates, Geocode (2010). *Rain gardens and biofiltration systems - A Study of Onsite Stormwater Management Potential in the Kingston, Knox, Port Phillip and Stonnington Local Government Areas,* report for Melbourne Water, july 2010, 20 p. + appendices (unpublished).

VSA (Swiss Water Association) (2002). *Directive sur l'infiltration, la rétention et l'évacuation des eaux pluviales dans les agglomérations,* VSA, novembre 2002, 119 p., updated 2008.

Woods-Ballard, B., Kellagher, R., Martin, P. et *al.* (2007). *The SUDS manual. C697.* CIRIA. London, 2007, 606 p.